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The portable remote vehicle controller (PRVC), recently developed at the Naval Command, Control and Ocean Surveillance Center's Research, Development, Test and Evaluation Division (NRaD) Detachment, Kailua, Hawaii, provides a lightweight, compact, teleoperator control station that allows remote, high speed control of unmanned ground vehicles (UGV). This ruggedized UGV operator control unit is configurable to work in any operating environment. Test drivers rated PRVC's ergonomically designed steering, brake and throttle controls superior to other driving configurations. All functional vehicle controls are easily accessible and can be manipulated by feel—without the need to look at physical buttons or levers. Graphic overlays displayed on the video image inform the UGV operator of critical system conditions and obviate the need to concentrate on other visual displays. Fiber optic data communications to the UGV, and RF audio communication to the military networks are fully supported by the PRVC.

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A PORTABLE CONTROLLER FOR UNMANNED GROUND VEHICLES

By Alan Y. Umeda, Thomas W. Hughes, Anthony H. Koyamatsu, Brian N. Nobunaga, Ken K. Yamada and Lloyd B. T. Yano

The portable remote vehicle controller (PRVC), recently developed at the Naval Command, Control and Ocean Surveillance Center's Research, Development, Test and Evaluation Division (NRaD) Detachment, Kailua, Hawaii, provides a lightweight, compact, teleoperator control station that allows remote, high speed control of unmanned ground vehicles (UGV). This ruggedized UGV operator control unit is configurable to work in any operating environment. Test drivers rated PRVC's ergonomically designed steering, brake and throttle controls superior to other driving configurations. All functional vehicle controls are easily accessible and can be manipulated by feel – without the need to look at physical buttons or levers. Graphic overlays displayed on the video image inform the UGV operator of critical system conditions and obviate the need to concentrate on other visual displays. Fiber optic data communications to the UGV, and RF audio communication to military networks are fully supported by the PRVC.

BACKGROUND

High speed UGV systems have recently been demonstrated in rugged, off-road environments. In 1985, the advanced teleoperator technology vehicle (ATTV), based on an off-road vehicle frame, was demonstrated at Ft. Lewis, Washington, and at the Kaneohe Marine Corps Air Station in Hawaii.[1] Using full-sized replicas of vehicle controls, the vehicle was remotely driven at speeds in excess of 45 kilometers per hour. As a follow-on to this effort, NRaD was tasked to develop three teleoperated vehicles (TOV).[2] As with the ATTV, TOV mobility was controlled by an operator through steering, brake and throttle replicas.[3] High speed transit through severe off-road terrain was tested at various test sites across the nation.

Field-portable operator control units for off-road UGVs have been built by several Government and commercial organizations. Sandia Laboratory used suitcase-sized units to control an array of vehicles.[4] Martin Marietta and Grumman demonstrated similar units for control of Teleoperated Mobile All-Purpose vehicles.[5]

NRaD recognized the need for downsized, field-portable, operator control units that allow operators to drive remote vehicles effectively at high speeds. New driving control concepts were needed to make small operator control units that could effectively pilot UGVs. Systems such as ATTV, TOV and others that used exact analogues of vehicle controls were effective in providing high speed remote driving capability but were generally too bulky and not portable. Other methods that used joysticks in smaller, more portable units were not suitable for high velocity maneuvering. The portable remote vehicle controller was developed as an experimental testbed for vehicle control mechanisms. Performance tests of concept driving controls were evaluated using an operational TOV and the results are discussed in the driving control experiments section.

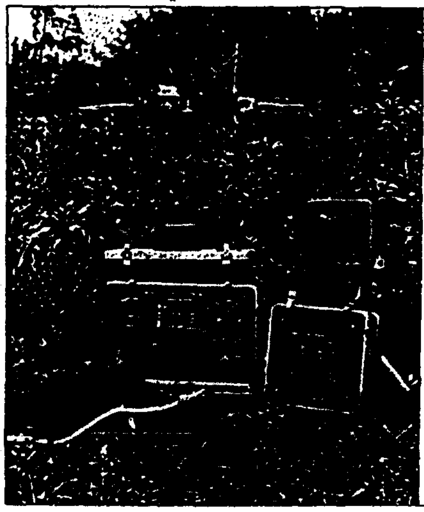
DESCRIPTION

General. NRaD's PRVC is a field-configurable operator control unit for UGVs. It is comprised of four major components:

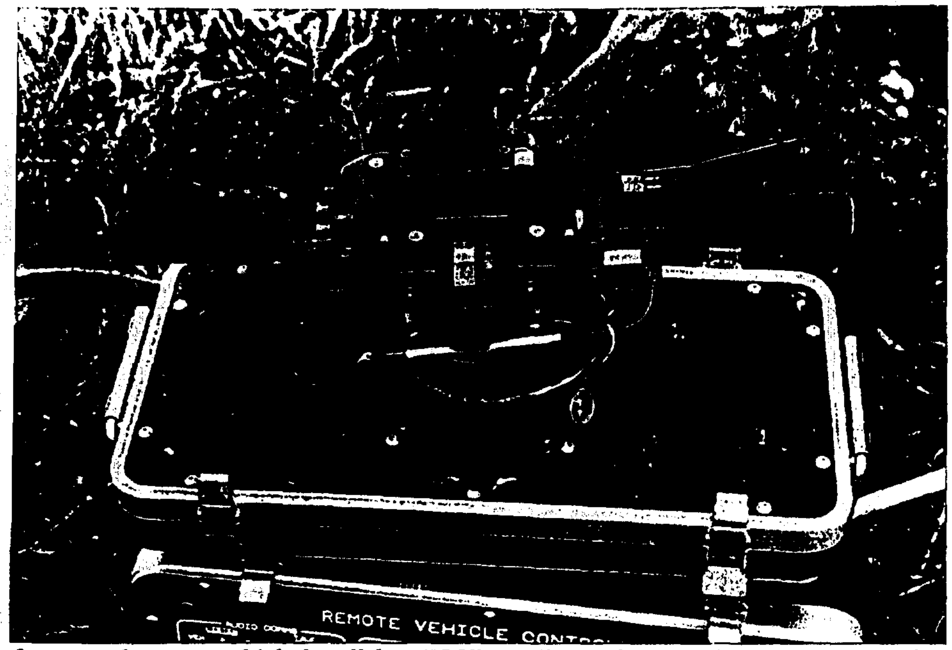
- Main Enclosure
- Integrated Remote Vehicle Handlebar (IRVH)
- Battery Pack
- Video Display.

A fifth component, the helmet-mounted display (HMD) is used with PRVC in typical operations.[6]

The PRVC is designed for quick setup in the field. It is built into four lightweight, fiberglass transport cases, each weighing less than 45 pounds.



Portable remote vehicle controller with teleoperated vehicle remote vehicle in background. The PRVC is capable of controlling the TOV via fiber optic data link. Vehicle controls are integrated on the handlebar and mission function controls are located on the front panel of the main enclosure. Graphics and text of selected status information is overlaid on the real-time video from the vehicle and displayed on the helmet mounted display and video monitor. The battery pack allows for six hours of continuous operation. An electric generator can be used to recharge the battery pack and to extend the mission duration.



Integrated remote vehicle handlebar (IRVH). All vehicle controls are located on this unit. Controls are similar to motorcycle controls. The steering handle has a $\pm 60^{\circ}$ turning capability with a torsional spring return to center. The right grip is for the throttle. Both brake levers are linked to the same hydraulic master cylinder. Vehicle lights, parking brake and horn are operated from the left handlebar. System power and remote start are operated from the right handlebar. The center hub is for the navigation graphics overlay select button, push-to-talk select button, and transmission drive select switches.

Modular components allow a variety of configuration options and operating positions. It is conceived that UGV operators will control the system from a sitting or prone position. PRVC equipment can accommodate these positions through proper arrangement of the components and can be deployed on any type of terrain including flat or sloping ground and in foxholes. This flexibility allows system deployment from defilade locations and operator comfort from customized layouts.

All PRVC components are packaged to withstand rugged outdoor environments. Electronic circuits are designed to operate in extreme temperatures and mechanical vibration. The enclosures are sealed to prevent dust and moisture from affecting internal components. Heat generated from electronic parts is transferred to the enclosure walls via card rack heat rails. Passive air cooling dissipates heat from the enclosure walls. Switches, connectors and displays located on the enclosure panels have seals to maintain the integrity of the sealed compartments.

Main Enclosure. The main enclosure has the bulk of the electronic systems, and includes the fiber optic data link, audio communications, processor, graphics overlay and power conversion electronics. The front panel of the Main Enclosure allows operator interaction with system functions. Controls are organized in functional clusters including: navigation keypad, audio communications, video, mission module mast platform and mission module.

The back panel has provisions for power, audio and video signal connectors, tactical radio interfaces and optical fiber terminations. A strain relief mechanism is provided to protect the fiber optic connector from accidental damage. Optical power is displayed on an LCD meter located above the optical connector.

A fiber optic data link provides the means of information transfer between the PRVC and the UGV. This data link allows real-time, bidirectional communications over a single optical fiber. Two video channels and binaural microphone inputs are digitized at the remote vehicle, then transmitted to the PRVC through the optical link. Command information for remote vehicle control is transmitted from the PRVC using one of several serial data channels.The audio communications system is a voice network that allows operator interaction with the military communication network, local observers and personnel near the UGV remote vehicle site. While driving the UGV, the

operator wears an HMD and has access to the audio network through the HMD binaural headphones and a microphone. Alternately, a lightweight headset or military handset can be used.

Tactical radio interfaces are fully supported when the military radio remoting set is connected to the PRVC. The remoting set attaches to the Main Enclosure unit through a handset connector. Local observers can gain access to the audio communications network by plugging a handset into the Main Enclosure unit.

Integrated Remote Vehicle Handlebar (IRVH). The integrated remote vehicle handlebar is the human-machine interface that gives the UGV operator complete control of UGV driving functions. Hand operated controls such as the steering handlebar, brake hand-levers and throttle grip are physically and functionally similar to motorcycle controls. Other switches on the IRVH control discrete vehicle functions. Navigation map pull-down and audio communication push-to-talk buttons are readily accessible.

The IRVH unit can be used in a wide variety of operating positions. Connection to the main enclosure is through a two meter long, multi-conductor cable. IRVH can be used in its case or removed and secured to any mounting structure. It is lightweight and small enough to allow laptop operation and has the structural integrity for operation on practically any surface. A preferred configuration places the IRVH on top of the main enclosure and allows comfortable operation in the sitting position.

IRVH's steering handle allows ±60 degrees of turning capability and uses an innovative compact torsional spring return centering device to provide a return force to center that is proportional to the angular offset from center. At 30 degrees deflection, the return torque is three foot-pounds.

Brake levers are linked to a hydraulic master cylinder. Large brake levers are provided for both right and left hands. A pressure transducer, connected to the master cylinder pressure line, senses the force applied to the brake levers. This is used to generate commands for proportional control of vehicle brakes. In this manner, the operator can relate forces exerted on the brake levers to UGV braking actions.

A wrist throttle grip provides proportional position control of the vehicle's throttle function. This rotary mechanism has 90 degrees travel and a torsional spring with a ten-pound return force.

Motorcycle parts are used for other IRVH functional controls. Ignition, starter, transmission shifter, four-wheel drive, park brake, emergency brake, lights and horn switches were selected and organized to facilitate manipulation by feel – without the need to look at the physical levers or buttons. This is accomplished by using switches with varied tactile characteristics and through differences in position.

Battery Pack. The battery pack contains a pair of rechargeable lead-acid gel cell batteries to power the PRVC. This sealed unit can supply power to the PRVC for up to six hours of operation. Power can also be derived from any 24-28 volt power source. The battery pack is configured to allow continuous operation through two output terminals, even when a charging unit is connected to the charge terminals. A built-in meter monitors battery voltage.

Video Display. The video display is a high resolution, color, CRT video monitor, mounted on an extendable tripod so that height and angular position of the display can be adjusted to suit operator viewing needs. It is used for non-driving surveillance, reconnaissance and target acquisition operations of the UGV.

Video overlay of graphics and text characters onto live video provide real-time status information to the operator. In order to reduce graphics clutter, data is selectively placed on the screen depending on the mode of operation. Only data that is pertinent to the selected mode is displayed. A systems status screen can be enabled to display all sampled variables. In addition, a navigation map can be displayed at any time with a push of a button.

During UGV driving operations, a helmet mounted display (HMD) is used to provide stereoscopic vision to the UGV operator. HMD interfaces are fully supported by the PRVC.

FIELD EVALUATION

Driving Control Experiments. NRaD evaluated four sets of prototype hardware in order to select optimal steering, brake and throttle configurations. Two of the prototypes – modified joystick and integrated steering wheel – were similar to hardware used with existing teleoperated, remotely controlled systems. The other two prototypes – motorcycle handlebar and pistol grip – were conceived and developed as alternatives to existing techniques. All of the prototypes, and a TOV control station, were tested in field exercises with a TOV remote vehicle. Two novice test operators performed a total of 13 timed drives on two off-road courses. Training time, driving efficiency, operator comfort, control sensitivity and driver confidence were evaluated for the different control mechanisms.

The IRVH final design was based on field evaluation of four prototype driving mechanisms. The steering mechanism consisted of a motorcycle handlebar with center return. Dual, pressure control brake levers were designed into the steering column. A wrist-actuated, spring return grip controlled the throttle function. Finally, all other switches and levers needed to remotely drive a vehicle were placed on the driving column, within fingertip reach.

The motorcycle handlebar steering mechanism was regarded as superior to the other mechanisms for portable applications. It provided responsive control of the TOV steering function and was comfortable to operate over extended driving periods. The center return force of the motorcycle handlebar provided useful kinesthetic feedback of steer angles to the operator. Its orientation eased driver fatigue by allowing drivers to rest their hands and arms on the hand grips. Conversely, the joystick and pistol grip steering mechanisms were found to be too sensitive and susceptible to oversteer. Cross coupling of steering, brake and throttle functions was a problem with the modified joystick and the pistol grip.

Brake levers that used pressure control (integrated steering wheel, motorcycle handlebar) were rated superior to position control levers (modified joystick, pistol grip). Pressure controlled brakes allowed improved braking action compared to position controlled brakes in a variety of maneuvers, including: quick slow-down, cornering and non-skid stops. Operators reported an improved awareness of the braking action through simulated kinesthetic feedback. Test drivers suggested

that brake levers be provided for both hands in order to improve driver comfort. TOV foot-operated brake pedals were judged to be more realistic and effective than any of the portable methods, but was not considered practical for portable applications.

The wrist-actuated throttle mechanism of the motorcycle handlebar was preferred to the trigger or joystick mechanisms. It was generally easier to learn than the other methods and appears to be "more natural" to operate.

PRVC Tests. The PRVC was tested with a UGV on rugged off-road courses. Several drivers participated in trial exercises that validated PRVC design concepts. Following brief set-up procedures (six minutes average), test operators were able to negotiate 50 degree inclines, park the UGV in a coned stall and achieve vehicle speeds in excess of 40 kilometers per hour.

IRVH driving controls allowed test operators to naturally maneuver the UGV through difficult off-road obstacles. The center return steering mechanism provided a positive indication of the steering angle with no cross-coupling from the other functions. Operators were able to confidently perform hard left/right steering actions with only 60-degree deflections of the handlebar, while retaining the sensitivity needed to maintain high UGV speeds. Vehicle braking was accurately controlled by the operators using the dual lever, pressure control brake handles. After a brief orientation period, operators were able to bring the UGV to quick, non-skid stops. The wrist-actuated throttle grip provided positive control of the throttle function.

Other UGV functions were easily engaged using switches mounted on the integrated steering column. The tactile diversity and position of the levers allowed test operators to find shift, brakes and other functions by feel. This feature was particularly valuable, since the operators could not afford to spend much time looking for switches, especially when using an HMD.

SUMMARY

NRaD's PRVC demonstrated the feasibility of high speed UGV control using portable, environment-adaptable equipment. PRVC was subjected to tests with a UGV operating in rugged, off-road terrain. Test drivers were able to maneuver the UGV through an off-road test course at high speeds and with a high degree of confidence.

Innovative driving control mechanisms were developed to provide operators with UGV functions using operator-friendly levers and switch configurations. Switches with tactile diversity were used to allow manipulation by feel, without the need for visual confirmation. Steering, brake and throttle functions were decoupled to prevent functional crosstalk while driving at high speeds and high cognitive loading.

Experiments with a variety of remote driving mechanisms showed that large, functionally decoupled mechanisms provided the best high speed performance results. These results also showed that the simulated steering, throttle and brake force feedback enhanced the operator's ability to control those critical vehicle functions.

Field exercises confirmed the need for ruggedized equipment designs with respect to temperature, mechanical shock/vibration and moisture/dust protection. PRVC hardware has been used repeatedly and reliably in field tests and exercises since its completion in early 1991.❊

End Notes

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FELICS DEMONSTRATED AT DEMO I

FELICS (Feedback Limited Control System), a patent pending technology developed by Dynamic System Technologies Incorporated (DSTI), was demonstrated at the Unmanned Ground Vehicles (UGVs) technology demo, known as DEMO I. DEMO I was conducted at Aberdeen Proving Ground in April and May 1992. FELICS is an advanced remote teleoperation technology that permits real-time, interactive operator control of UGVs when only very low data rate video channels are available. FELICS control was demonstrated on a variety of terrains and at a range of speeds.

FELICS permits operation with very low frame-rate video, effectively reducing the data rate requirement. A rate of 3.5 seconds between frames was demonstrated at DEMO I. The demonstration system utilized a 300 kilobits/second RF channel for video, data and command. With the addition of a currently available video compressor, data channels of less than six kilobits/second can be achieved.

The demonstration system was installed on a company owned six-wheel, amphibious, all-wheel drive, skid-steer vehicle. The control station was installed in a standard 1/2-ton van. FELICS boasts the need for very little computer capability – the demonstration system used a PC/AT compatible in the control station and one in the vehicle. The operator interface primarily uses only two control axes. This simple-to-operate system requires only minutes of operator training.

DSTI is offering a turn-key teleoperated system which includes an 8-wheeled vehicle and a portable control station. The RF data link requires no FCC licensing for operation. The vehicle includes a pan and tilt camera and mast that collapses for transportation. For more information, call Wadi Rahim of Dynamic System Technologies Incorporated, 8205B Cloverleaf Drive, Millersville, MD 21108 – (410) 544-5143.❊